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New Information on Age and Growth of Yellowtail Flounder in Divisions 3LNO as Determined from Tag Returns

by

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Introduction

Yellowtail flounder on the Grand Banks, NAFO Divisions 3LNO, has always been perceived as a relatively fast growing species with a short lifespan of 12 years (Pitt 1974; Walsh et al. 1998). Pitt (1970) from a comparative analysis concluded that yellowtail from the Grand Banks and Scotian Shelf areas had similar growth rates, both of which were slower than those measured for the New England stocks. Since 1991 yellowtail older that 9 years have been absent from the age readings of annual research trawl surveys. Cropping off of older ages by the intense fishery from 1985 to 1993 when catch often doubled the TAC set for that year could be one explanation (see Walsh et al. 1998). Another explanation could be a problem in age reading whereby ages of older fish are underestimated. Often independent data on age and growth are not available to serve as a validation for aging. However, a limited number of tag returns, from traditional Petersen disc experiments carried out from 1990-93 have been returned from commercial fisheries before, during and after the fisheries moratorium (1994-97) (Morgan and Walsh 1999) Several returns included size measurements upon capture and in some cases included the otoliths.

The purpose of this paper is to present new information on age and growth of yellowtail flounder on the Grand Banks as determined from tag return data.

Materials and Methods

Yellowtail flounder were tagged and released in the area of the tail of the Grand Bank in NAFO Div. 3LNO during four research vessel trips from 1990 to 1993. Fish were captured using a Yankee 41 shrimp trawl that was towed for 15 minutes at a speed of 2.5 knots. Fish were placed in holding tanks and then tagged and total length measured. Only fish between 15 and 35 cm were tagged so that mainly juveniles were released. Any fish with excessive bruising or scale loss were not tagged. The fish were returned to a holding tank after tagging and held until the release position was reached. There were 9 release positions, 6 inside Canada's 200 mile limit and 3 outside the 200 mile limit.

When tags were returned the return information was entered into a data base and a $20 reward sent to the person returning the tag. A subset of the returned tags included information on fish length. Only returns where the return length was greater than or equal to the release length were included. A total of 108 returns fit this criterion. These returns were divided into reliability categories depending on who had collected the length information. Returns in reliability category 1 had been collected by scientists during research vessel trips or by scientists sampling landings at Canadian. Returns in reliability category 2 had been returned by Canadian-non Canadian fishery observers or Canadian surveillance officers onboard ships at sea and included such information as weight or maturity stage, but it was not certain that these people had actually been the ones to collect the information. Returns in reliability category 3 were collected and returned by fishers. Growth rate (cm/ yr) was compared among reliability categories using an ANOVA by ranks. Then mean growth was determined. As well, the effect on growth of number of years at liberty and of release year was examined. All analyses excluded 4 returns (all in reliability category 3) which had apparent growth rates of more than 30 cm per year.

Nineteen otoliths and recapture lengths were returned with the tags. These otoliths were given, minus information about length, to the primary otolith reader who aged them under a microscope. Using a age-length regression and the initial size at tagging a predicted age at tagging was developed. Using the number of years free after tagging, an estimated age at recapture was derived which was then compared with the ages read from the returned otoliths. The von Bertalanffy's growth parameter *K* was estimated from the tagging data by fitting a growth curve to data representing unequal time intervals using the method of Gulland and Holt (1959) and described in detail by Jones (1976) (see Appendix I for model description)

Results

A total of 108 returns had acceptable length information. There was no significant difference between reliability categories in mean growth per year ($\chi^2 = 0.5$, df=2, NS) therefore returns in all reliability categories were combined in further analyses.

The average growth over the time period was found to be 1.7 ± 2.1 cm/year (Fig. 1). There was no significant effect of release year on growth rate ($\chi^2 = 7.6$, df=4, $p>.05$). There was a significant effect of number of years at liberty on growth rate ($\chi^2 = 16.6$, df=7, $p<0.025$), however, there was no consistent trend (Fig. 1)

Table 1 gives the output from the modified von Bertalanffy growth model. After one interation the growth parameter K (K_1) was estimated to be 0.07. Table 2 compares the summary of parameters of von Bertalanffy's growth equation for yellowtail flounder from different geographic areas in the Northwest Atlantic based on age data. The estimation of growth rate K from the tag returns is extremely low by comparison with values derived from the literature. Here, K ranges from 0.13 to .41 with and average of .25 indicative of a fast growing species.

From the tagging data, 19 otoliths were returned with information on length at re-capture (Table 2). Figure 2 shows a plot of average length-at-age from age data derived from the 1984 to 1997 spring, fall and juvenile groundfish surveys for males and females (see Walsh et al 1998). Average growth of each year class is estimated to be 5 cm per year for all ages and no difference is indicated in males and females. Maximum age for males is 9 yrs and females 10 yrs in this database. Otoliths returned with the tagging information were read and data plotted in Figure 3 along with estimated age at recapture based on the number of years free and the predicted age at tagging (using mean length at age relationship in Fig. 2). Otolith age reading of returned otoliths placed the age range from 6 to 9 years while the estimated age of these recaptures ranged from 7 to 14 years (Table 2). There maybe a tendency for a difference in age reading and the estimated age to increase with length of the fish.

Table 3 shows the number of ages derived from the NAFC research vessel otolith collection by year starting in 1949. In earlier years there were some yellowtail flounder aged above 10 years of age over the time series until 1985. After 1991 no yellowtail flounder were aged above 9 yrs.

Discussion

This low growth rate determined from yellowtail flounder tag returns would be typical of a slow growing long lived species like American plaice (*Hippoglossoides platessoides*) where K ranges from 0.06 to 0.18 for populations in the Northwest Atlantic, being faster growing in the southern area (Walsh 1994). Our estimation of average growth of 5 cm per year is closer to historic estimates of growth derived for populations on St. Pierre Bank, Scotian Shelf, and New England Banks (see Table 2 for reference) Traditionally, yellowtail growth curves are curvilinear and von Bertanlanffy growth models fit well while our present age-length data indicate a strong linear trend.

Several factors may contribute to the differences in growth rates derived from tag data and aging data. The obvious would be an aging problem with the otolith reading at NAFC whereby the older ages are underestimated. The accuracy of otolith aging needs to be determined. This can be accomplished by setting up a reference collection whereby the primary age reader can compare his age readings with those of previous age readers. In addition an aging workshop should be set up with readers from other institutes to determine a consensus. Finally other aging techniques such as frequency analysis and radiochemical age validation techniques (see Campana et al. 1990) are required for independent age validation and accuracy determination. Along with the otolith research more tagging data is needed to determine whether the slow growth rates are reflective of the true population growth. Several of these fish were at liberty during the downturn in the stock size and through the fishing moratorium. During this time, one would expect some density dependent changes in growth. Growth rates in the range of those estimated from the tagged fish make it difficult to explain the large increases in biomass since 1994 (Walsh et al. 1999). A new and extensive tagging program could provide some insight into growth of yellowtail flounder on the Grand Bank.

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Table 1   Estimation of growth parameter K from yellowtail flounder tagging data (see Apendix I for description)

	a	**Lt**	**Lt+a**	**y**	**x**	**b1**			
Tag No.	Years Free	Tag size	Capture size	Lt+a-Lt/a	Lt+a+lt/2	1/2K1*a	tanh b1	b1/tan h(b1)	y*(b1/tan b1)
s1425	2.814	24	27.9	1.39	26.0	-0.10	-0.10	1.00	1.4
s1051	3.918	24	34	2.55	29.0	-0.14	-0.14	1.01	2.6
s2089	3.811	23	31	2.10	27.0	-0.13	-0.13	1.01	2.1
s06675	1.364	26	28	1.47	27.0	-0.05	-0.05	1.00	1.5
s06706	3.318	27	39	3.62	33.0	-0.12	-0.12	1.00	3.6
s06955	1.956	31	34	1.53	32.5	-0.07	-0.07	1.00	1.5
s08003	1.019	26	28	1.96	27.0	-0.04	-0.04	1.00	2.0
s07044	1.137	29	35.6	5.80	32.3	-0.04	-0.04	1.00	5.8
s07137	0.304	26	26	0.00	26.0	-0.01	-0.01	1.00	0.0
s07247	2.107	30	37	3.32	33.5	-0.07	-0.07	1.00	3.3
s07615	2.0	30	34	2.00	32.0	-0.07	-0.07	1.00	2.0
s06800	2.299	32	35	1.30	33.5	-0.08	-0.08	1.00	1.3
s06408	3.025	31	33	0.66	32.0	-0.11	-0.11	1.00	0.7
s06039	0.458	30	31	2.18	30.5	-0.02	-0.02	1.00	2.2
s06385	2.797	27	35	2.86	31.0	-0.10	-0.10	1.00	2.9
s07232	3.31	30	37	2.11	33.5	-0.12	-0.12	1.00	2.1
s07269	3.293	28	34	1.82	31.0	-0.12	-0.11	1.00	1.8
s06999	3.175	26	35.6	3.02	30.8	-0.11	-0.11	1.00	3.0
s07246	3.258	29	34	1.53	31.5	-0.11	-0.11	1.00	1.5
s07483	3.244	28	30	0.62	29.0	-0.11	-0.11	1.00	0.6
s06314	3.332	29	38	2.70	33.5	-0.12	-0.12	1.00	2.7
y00177	2.288	29	32	1.31	30.5	-0.08	-0.08	1.00	1.3
y00015	2.055	29	33	1.95	31.0	-0.07	-0.07	1.00	1.9
y00021	0.17	37	37	0.00	37.0	-0.01	-0.01	1.00	0.0
y00030	1.211	31	33	1.65	32.0	-0.04	-0.04	1.00	1.7
y00046	0.263	32	32	0.00	32.0	-0.01	-0.01	1.00	0.0
y00048	0.093	24	24	0.00	24.0	0.00	0.00	1.00	0.0
y00049	1.093	38	39	0.91	38.5	-0.04	-0.04	1.00	0.9
y00061	0.258	31	31	0.00	31.0	-0.01	-0.01	1.00	0.0

Table 1
Cont'd

	a	**Lt**	**Lt+a**	**y**	**x**	**b1**			
Tag No.	Years Free	Tag size	Capture size	Lt+a-Lt/a	Lt+a+lt/2	1/2K1*a	tanh b1	b1/tan h(b1)	y*(b1/tan b1)
y00113	1.186	37	37	0.00	37.0	-0.04	-0.04	1.00	0.0
y00134	0.038	27	27	0.00	27.0	0.00	0.00	1.00	0.0
y00160	0.156	27	27	0.00	27.0	-0.01	-0.01	1.00	0.0
y02212	1.342	27	35	5.96	31.0	-0.05	-0.05	1.00	6.0
y02893	0.249	31	31	0.00	31.0	-0.01	-0.01	1.00	0.0
y02905	0.279	36	37	3.58	36.5	-0.01	-0.01	1.00	3.6
y02907	0.26	31	31	0.00	31.0	-0.01	-0.01	1.00	0.0
y01155	2.192	34	37	1.37	35.5	-0.08	-0.08	1.00	1.4
y00293	2.301	33	40	3.04	36.5	-0.08	-0.08	1.00	3.0
y02862	1.964	33	36	1.53	34.5	-0.07	-0.07	1.00	1.5
y00731	2.252	32	36	1.78	34.0	-0.08	-0.08	1.00	1.8
y01282	2.31	27	41	6.06	34.0	-0.08	-0.08	1.00	6.1
y01765	2.079	35	36	0.48	35.5	-0.07	-0.07	1.00	0.5
y02234	2.164	28	33	2.31	30.5	-0.08	-0.08	1.00	2.3
y00637	2.241	33	37	1.78	35.0	-0.08	-0.08	1.00	1.8
y01403	2.227	31	35	1.80	33.0	-0.08	-0.08	1.00	1.8
y01749	2.159	32	38.1	2.83	35.1	-0.08	-0.08	1.00	2.8
y01754	1.984	32	36	2.02	34.0	-0.07	-0.07	1.00	2.0
y00334	0.953	30	31	1.05	30.5	-0.03	-0.03	1.00	1.0
y00544	1.277	30	32	1.57	31.0	-0.04	-0.04	1.00	1.6
y00581	0.392	31	31.2	0.51	31.1	-0.01	-0.01	1.00	0.5
y00926	0.351	29	30	2.85	29.5	-0.01	-0.01	1.00	2.8
y01268	0.263	28	31	11.41	29.5	-0.01	-0.01	1.00	11.4
y01319	0.255	31	31	0.00	31.0	-0.01	-0.01	1.00	0.0
y01362	1.068	35	35	0.00	35.0	-0.04	-0.04	1.00	0.0
y01545	0.34	30	30	0.00	30.0	-0.01	-0.01	1.00	0.0

Table 1 cont'd

	a	**Lt**	**Lt+a**	**y**	**x**	**b1**			
Tag No.	Years Free	Tag size	Capture size	Lt+a-Lt/a	Lt+a+lt/2	1/2K1*a	tanh b1	b1/tan h(b1)	y*(b1/tan b1)
y01942	1.238	32	34	1.62	33.0	-0.04	-0.04	1.00	1.6
y01960	1.981	28	32	2.02	30.0	-0.07	-0.07	1.00	2.0
y02135	0.348	28	29	2.87	28.5	-0.01	-0.01	1.00	2.9
y02188	1.208	33	35	1.66	34.0	-0.04	-0.04	1.00	1.7
y02193	1.118	30	33	2.68	31.5	-0.04	-0.04	1.00	2.7
y02200	0.332	33	33	0.00	33.0	-0.01	-0.01	1.00	0.0
y05158	1.033	32	35	2.90	33.5	-0.04	-0.04	1.00	2.9
y05370	1.167	33	33	0.00	33.0	-0.04	-0.04	1.00	0.0
y04636	1.093	31	32	0.91	31.5	-0.04	-0.04	1.00	0.9
y05310	1.216	30	31	0.82	30.5	-0.04	-0.04	1.00	0.8
y04357	0.984	31	32	1.02	31.5	-0.03	-0.03	1.00	1.0
y04943	0.005	32	32	0.00	32.0	0.00	0.00	1.00	0.0
y05213	0.005	35	35	0.00	35.0	0.00	0.00	1.00	0.0
y05320	0.268	35	35	0.00	35.0	-0.01	-0.01	1.00	0.0
y04006	1.299	30	31	0.77	30.5	-0.05	-0.05	1.00	0.8
y06222	0.156	32	32	0.00	32.0	-0.01	-0.01	1.00	0.0
y06270	0.29	25	25	0.00	25.0	-0.01	-0.01	1.00	0.0
y06494	0.293	27	27	0.00	27.0	-0.01	-0.01	1.00	0.0
y06116	0.296	22	23	3.38	22.5	-0.01	-0.01	1.00	3.4
y06012	0.29	23	24	3.45	23.5	-0.01	-0.01	1.00	3.4
y05899	0.29	26	30	13.79	28.0	-0.01	-0.01	1.00	13.8
y06812	0.148	29	29	0.00	29.0	-0.01	-0.01	1.00	0.0
y06697	0.31	31	31	0.00	31.0	-0.01	-0.01	1.00	0.0

Table 1 cont'd

	a	**Lt**	**Lt+a**	**y**	**x**	**b1**			
Tag No.	Years Free	Tag size	Capture size	Lt+a-Lt/a	Lt+a+lt/2	1/2K1*a	tanh b1	b1/tan h(b1)	y*(b1/tan b1)
y07192	1.932	31	32	0.52	31.5	-0.07	-0.07	1.00	0.5
y07093	1.244	30	32.5	2.01	31.3	-0.04	-0.04	1.00	2.0
y05926	5.145	27	34	1.36	30.5	-0.18	-0.18	1.01	1.4
s07132	8.175	24	33	1.10	28.5	-0.29	-0.28	1.03	1.1
y04449	6.197	26	46	3.23	36.0	-0.22	-0.21	1.02	3.3
y01914	7.197	34	42	1.11	38.0	-0.25	-0.25	1.02	1.1
s06346	8.266	27	36	1.09	31.5	-0.29	-0.28	1.03	1.1
y05074	6.263	31	34	0.48	32.5	-0.22	-0.22	1.02	0.5
y01094	7.263	32	38	0.83	35.0	-0.25	-0.25	1.02	0.8
y06281	2.934	28	36.5	2.90	32.3	-0.10	-0.10	1.00	2.9
y05145	3.945	33	37	1.01	35.0	-0.14	-0.14	1.01	1.0
y04389	3.945	35	37	0.51	36.0	-0.14	-0.14	1.01	0.5

Location	Data Type	Sex	Ages fitted	Loo	K	to	Reference
Grand Bank	Commercial	F	4 to 10	52.96	0.24	0.86	Pitt 1974
Grand Bank	Commercial	M	4 to 12	46.40	0.32	1.16	Pitt 1974
Grand Bank	Commercial	M+F	4 to 12	50.20	0.28	0.63	Pitt 1974
Grand Bank	Research	F	3 to 12	48.12	0.29	0.80	Pitt 1974
Grand Bank	Research	M	3 to 11	42.07	0.41	1.39	Pitt 1974
Scotian Shelf	Research	M+F	4 to 11	52.00	0.26	1.29	Pitt 1974 calculations from Scott' 1954 data
New England	Commercial	M+F	2 to 7	50.00	0.34	-0.26	Lux and Nichy 1969
St Pierre Bank	Research	M	2 to 8	48.38	0.15	0.50	Berthome 1976
St Pierre Bank	Research	F	2 to 9	56.44	0.13	0.50	Berthome 1976
Grand Bank	**Tag returns**	**M+F**			**0.07**		**This Study**

Table 3 Reconstructed age of yellowtail flounder from tagging returns

Tag No.	Days Free	Years Free	Size at tagging (cm)	Pred. Tag age (yr.)	Capture size (cm)	Age of recaptures (yr.)	Growth (cm)	Estimated age of capture (yr.)
S07232	1207	3.3	30	6	37	7	7	9
S07269	1201	3.3	28	5	34	6	6	8
S07246	1188	3.3	29	6	34	7	5	9
Y00177	834	2.3	29	6	32	8	3	8
Y00030	441	1.2	31	6	33	6	2	7
Y00731	821	2.2	32	6	36	6	4	8
Y01403	812	2.2	31	6	35	7	4	8
Y00544	465	1.3	30	6	32	7	2	7
Y01960	722	2.0	28	5	32	6	4	7
Y04006	474	1.3	30	6	31	5	1	7
Y01792	797	2.2	27	5	31	8	4	7
Y6371	1934	5.3	28	7	39	8	11	12
S07132	2982	8.2	24	6	33	6	9	14
S06346	3015	8.3	27	5	36	7	9	13
Y01094	2649	7.3	32	6	38	9	6	13
S07491	2979	8.2	30	6	40	8	10	14
Y6281	1069	2.9	28	5	37	6	9	8
Y06145	1439	3.9	33	6	37	8	4	10
Y04389	1439	3.9	35	7	37	7	2	11

Length =a+bx where a=0.0 and b=5.3   Used to get predicted age at tagging
Age of recapture from otolith reading
Estimated age of capture is sum of predicted age at tagging plus number of years free

Table 4 Listing of the number of otoliths in each age class in the Northwest Atlantic Fisheries Center research vessel otolith collection from 1949-96

age/year	49	50	51	52	53	61	63	64	65	66	67	68	69	70	71	72	73	74	75
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	5	0	2	0
3	0	0	3	0	0	0	0	0	3	6	6	1	6	32	10	68	7	19	5
4	0	4	13	1	1	18	0	0	12	40	32	10	24	87	111	187	56	90	48
5	2	7	12	2	4	19	0	4	18	45	162	54	121	236	230	286	221	163	121
6	23	7	17	5	16	37	0	13	4	79	199	66	126	470	336	272	195	191	116
7	23	25	15	10	24	41	0	49	4	67	149	61	152	328	317	241	227	185	126
8	40	56	29	11	50	50	0	25	2	57	51	41	91	119	71	97	104	73	61
9	15	9	10	7	47	18	0	13	9	39	20	7	25	19	23	15	55	24	21
10	11	4	12	3	28	3	0	7	3	15	11	1	8	3	1	3	15	1	4
11	2	1	3	0	13	1	0	0	2	2	0	0	2	0	0	0	3	0	0
12	4	0	0	0	8	1	0	1	4	5	3	0	0	0	0	0	2	0	0
13	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

age/year	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
1	0	0	0	3	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	49	24
2	1	0	2	4	7	19	39	0	0	1	0	135	2	13	3	8	6	2	1	122	129
3	50	4	25	24	109	64	80	0	6	34	2	139	9	39	42	37	37	16	14	119	235
4	54	21	58	98	131	88	127	0	40	96	21	135	37	84	132	127	95	115	62	136	189
5	138	73	158	167	259	140	213	48	124	174	119	229	78	91	200	193	155	139	125	190	201
6	161	117	257	282	334	275	190	124	270	413	239	305	166	163	218	250	193	232	194	303	269
7	246	235	262	459	410	291	355	167	362	593	480	353	293	287	313	339	262	288	231	341	325
8	161	234	183	281	250	268	412	151	305	536	420	362	290	244	288	266	215	263	223	379	351
9	54	112	61	81	34	111	245	80	126	161	128	147	137	82	89	99	70	91	21	20	23
10	10	34	27	16	1	36	79	44	19	39	12	24	9	12	15	1	0	0	0	0	0
11	1	5	7	0	0	4	10	0	0	1	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

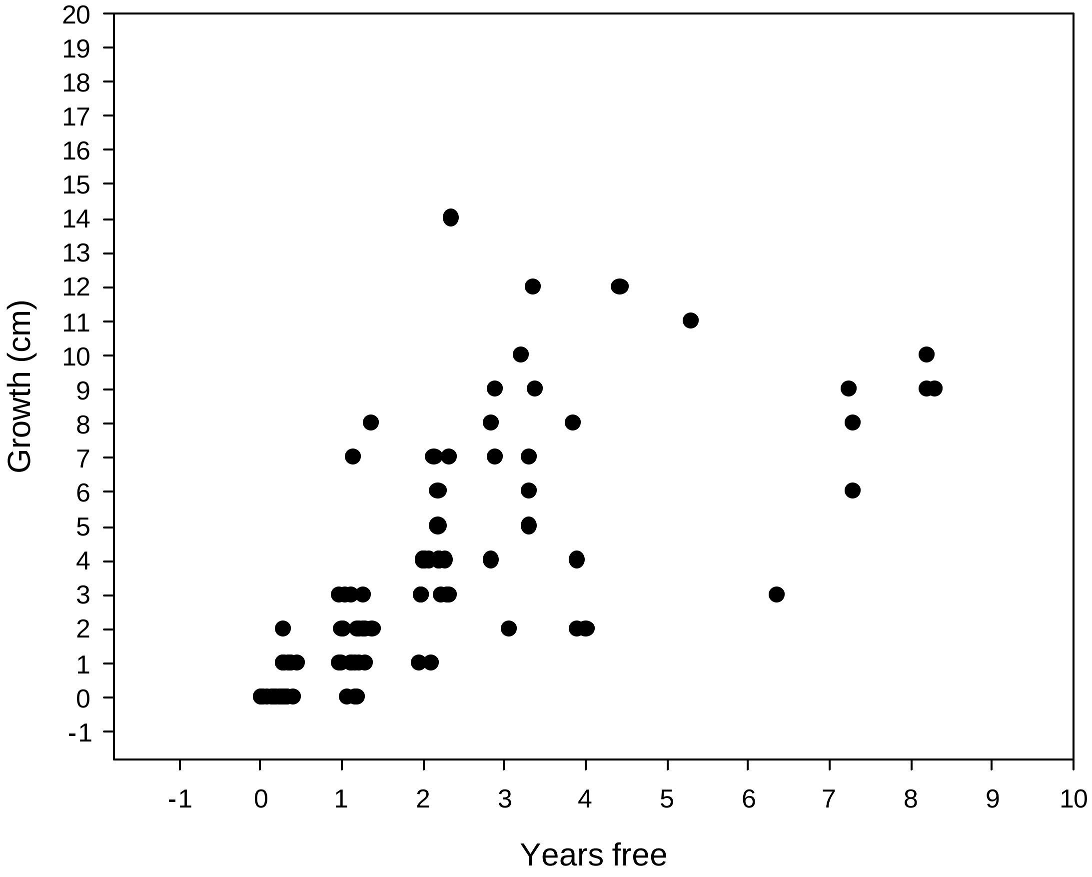


Fig. 1 Growth of yellowtail flounder from all tagging data.

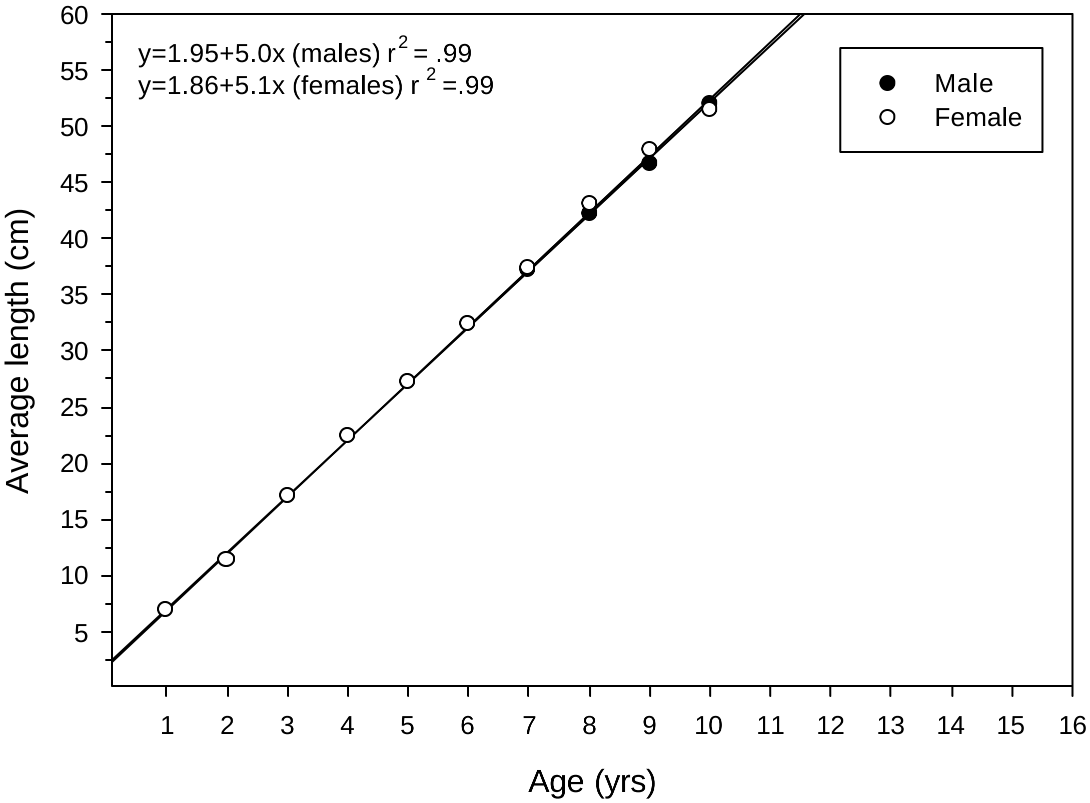


Fig. 2 Growth of yellowtail flounder on the Grand Bank based on average length data from spring, fall and juvenile research bottom trawl surveys

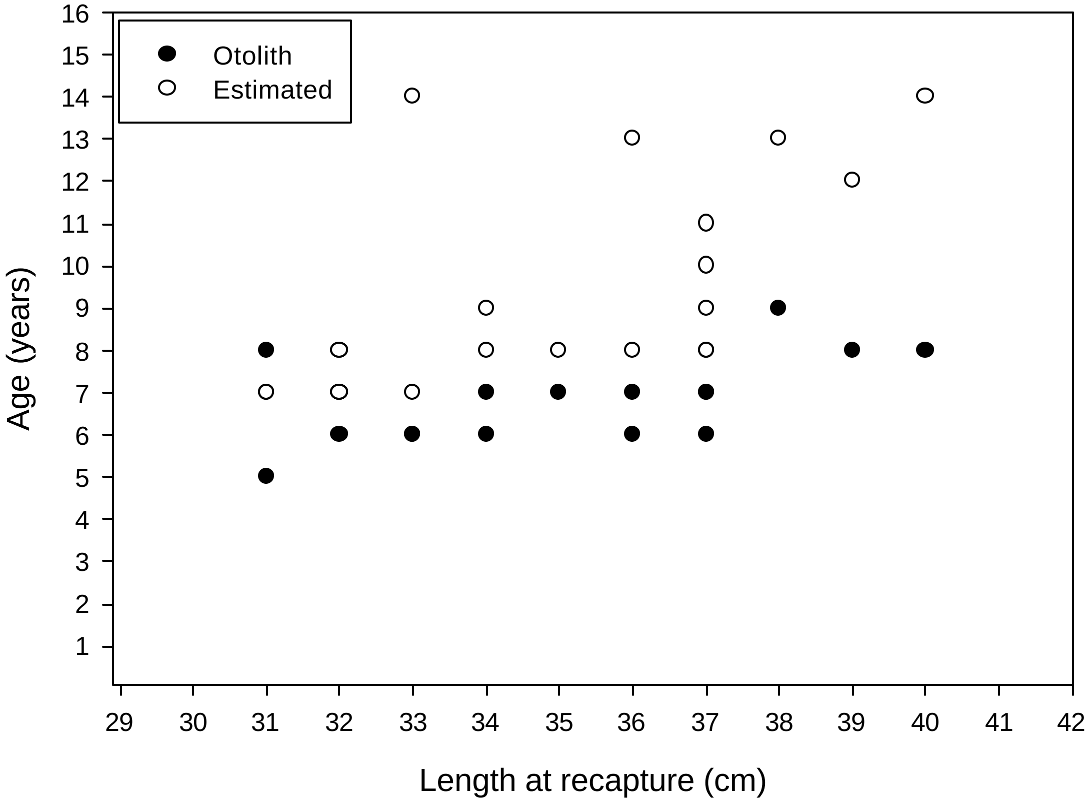
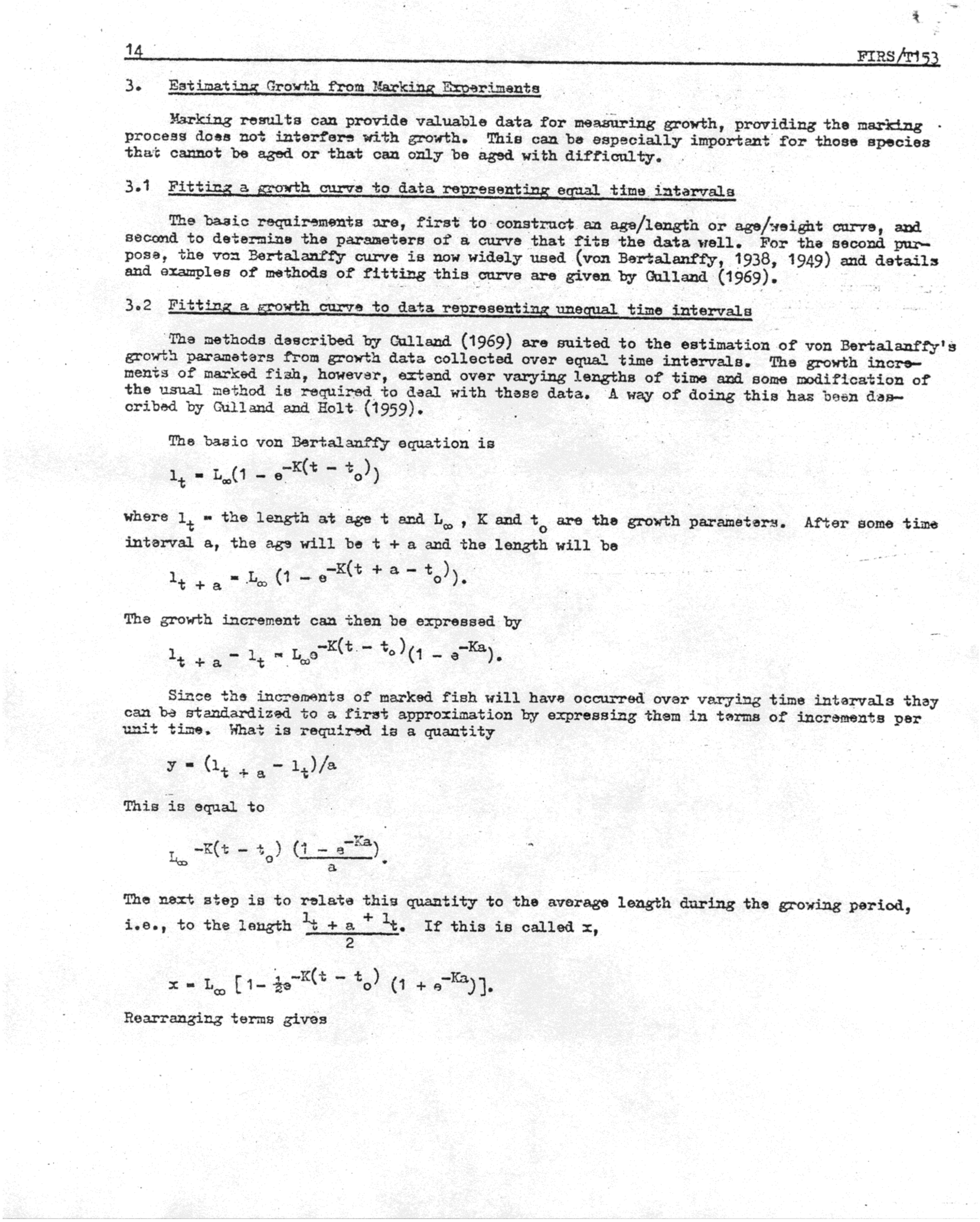


Fig. 3 Comparison of yellowtail flounder ages derived from otoliths returned with the tag and estimated age which is the sum of predicted age from mean length at age key and the number of years free.

APPENDIX I

Method to determined growth parameter K is reprinted here from Jones 1976.



3. Estimating Growth from Marking Experiments

Marking results can provide valuable data for measuring growth, providing the marking process does not interfere with growth. This can be especially important for those species that cannot be aged or that can only be aged with difficulty.

3.1 Fitting a growth curve to data representing equal time intervals

The basic requirements are, first to construct an age/length or age/weight curve, and second to determine the parameters of a curve that fits the data well. For the second purpose, the von Bertalanffy curve is now widely used (von Bertalanffy, 1938, 1949) and details and examples of methods of fitting this curve are given by Gulland (1969).

3.2 Fitting a growth curve to data representing unequal time intervals

The methods described by Gulland (1969) are suited to the estimation of von Bertalanffy's growth parameters from growth data collected over equal time intervals. The growth increments of marked fish, however, extend over varying lengths of time and some modification of the usual method is required to deal with these data. A way of doing this has been described by Gulland and Holt (1959).

The basic von Bertalanffy equation is

$$l_t = L_\infty(1 - e^{-K(t - t_o)})$$

where l_t = the length at age t and L_∞, K and t_o are the growth parameters. After some time interval a, the age will be t + a and the length will be

$$l_{t+a} = L_\infty (1 - e^{-K(t + a - t_o)}).$$

The growth increment can then be expressed by

$$l_{t+a} - l_t = L_\infty e^{-K(t - t_o)}(1 - e^{-Ka}).$$

Since the increments of marked fish will have occurred over varying time intervals they can be standardized to a first approximation by expressing them in terms of increments per unit time. What is required is a quantity

$$y = (l_{t+a} - l_t)/a$$

This is equal to

$$L_\infty{}^{-K(t - t_o)} \frac{(1 - e^{-Ka})}{a}.$$

The next step is to relate this quantity to the average length during the growing period, i.e., to the length $\frac{l_{t+a} + l_t}{2}$. If this is called x,

$$x = L_\infty [1 - \tfrac{1}{2}e^{-K(t - t_o)} (1 + e^{-Ka})].$$

Rearranging terms gives

$$L_\infty e^{-K(t - t_o)} = \frac{2(L_\infty - x)}{1 + e^{-Ka}}.$$

Next, substituting the expression for y above, gives

$$y = (L_\infty - x)\, \frac{2(1 - e^{-Ka})}{a(1 + e^{-Ka})}.$$

Finally, putting $\frac{1}{2}Ka = b$ gives

$$y = K(L_\infty - x)\, \frac{\tanh b}{b}$$

where $\tanh b = \left(\frac{1 - e^{-2b}}{1 + e^{-2b}}\right)$

or, alternatively

$$y\, \frac{b}{\tanh b} = K\, L_\infty - K\, x$$

From this equation it is clear that if $y\, \frac{b}{\tanh b}$ can be plotted against x, the result should be a straight line with a slope of −K and an intercept of $K\, L_\infty$.

An example is given in Table 20. The data in the first three columns are the recapture details for five fish. The values of y, the increment per unit time, and x, the mid point of each growing period, are calculated as shown. The next step is to plot y against x. The points will be found to lie on a straight line with a slope of −0.2. The first estimate of K which can be called K_1 is therefore 0.2. Using this value for K, b_1 can be calculated for each fish and the values of $\frac{b_1}{\tanh b_1}$ can be calculated or looked up in the table given by Gulland and Holt (1959). In the last column of Table 19 are shown the values of $\frac{y\, b_1}{\tanh b_1}$ for each fish.

In this example, the values of $\frac{b_1}{\tanh b_1}$ are so close to unity that the values in the last column of Table 19 are effectively the same as those of y. If they had not been the same, the procedure would have been to plot $\frac{y\, b_1}{\tanh b_1}$ against x to obtain a new line with a new slope. The slope of this line would have given a second estimate of $K(K_2)$ and the whole process could then have been repeated until the estimates of K remained unchanged. In practice, it should be noted that for values of b up to about 0.4, the values of $\frac{b}{\tanh b}$ remain close to unity so that a value of K can usually be obtained, as in this example, directly from the first plot of y against x.

When y is plotted against x using the above data, the line is seen to cut the x axis at a length of 90 cm. In other words, at a length of 90 cm the growth increment is zero, so that 90 cm is the required estimate of L_∞.

The parameter t_o cannot be estimated from the data given in Table 19 alone. It is also necessary to know the age of the fish at each of the 10 lengths recorded. If this is known, 10 values of t_o may be determined, one from each length, and the values averaged to give a single value of t_o. Details are given by Gulland (1969).

Table 20

Example of the estimation of growth parameters from tagging data

a	Lt	L_{t+a}	y	x	b_1		
Time of liberty (years)	Length at release (cm)	Length at recapture (cm)	$\frac{L_{t+a} - Lt}{a}$	$\frac{L_{t+a} + Lt}{2}$	$\frac{1}{2}K_1 a$	$\frac{b_1}{\tanh b_1}$	$y \cdot \frac{b_1}{\tanh b_1}$
0.5	9.1	16.9	15.6	13	0.05	1.0008	15.6
0.8	24.2	33.8	12.0	29	0.08	1.0021	12.0
1.0	41.5	50.5	9.0	46	0.10	1.0033	9.0
0.4	61.9	64.1	5.5	63	0.04	1.0005	5.5
1.2	74.2	77.8	3.0	76	0.12	1.0048	3.0

References

Gulland, J.A. ans S.J. Holt 1959 Estimation of growth parameters for data at unequal time intervals. J. Cons. CIEM. 25:47-49.

Jones R. The use of marking data in fish population analysis. FAO Fish. Tech. Pap. 153: 41p